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CONTENT

Controlled traffic farming as a strategy to reduce compaction risks

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Abstract
Reducing the risk of soil compaction asks for machinery adapted to the limitations of soil strength in the single wheel track, but also for strategies of field traffic organization to control the distribution of wheel tracks in the field. On the other hand promoting soil structure formation is closely linked to tillage practices and the degree of mechanical structure disturbance. Studying the combined effects of different field traffic organizations and tillage practices on structural development of arable soils and on crop development is the aim of a field experiment at Tänikon, Switzerland. In this article, the concept of soil management treatments combining random and controlled field traffic with plough tillage and no-tillage is presented. First results three years after the start of the field experiment show that effects on soil structure caused by these combinations of tillage/seeding technique and field traffic organisation are not very clear-cut yet.
Keywords: Soil compaction, field traffic organisation, tillage system, soil structure evolution, macropore volume, air permeability, yield

Introduction

Sustainable soil management relies on the proper maintenance of soil structure. This means on the one hand reducing the risk of soil compaction and on the other hand promoting the formation of soil structure.

Reducing the risk of soil compaction asks for machinery adapted to the limitations of soil mechanical properties. To this end the size and load of the contact area between machine and soil have to be controlled, optimizing machinery properties like arrangement of wheels, wheel load, tyre type, tyre dimension and inflation pressure. At the same time the consideration of soil structural strength during field operations, especially its short term aspect related to soil moisture, is crucial for reducing the risk of structure deterioration (Alakukku et al. 2003). Besides these efforts to reduce mechanical impacts in the single wheel track, there is also the important goal of reducing mechanical impacts on the whole managed field area, calling for strategies of field traffic organization (Chamen 2006).

Promoting soil structure formation in order to alleviate structural damages and to improve structural quality is closely linked to tillage practices. Especially the degree of mechanical disturbance, or soil loosening, is important for the equilibrium between stability and functionality of soil structure. Effects of different tillage intensities on the properties and the evolution of soil structure are elements of many field experiments comparing e.g. plough tillage to no tillage (Anken 2003).

Whereas the assessment of soil compaction risk in wheel tracks and the corresponding adaptation of farm machinery are well known and part of good management practices (Stettler et al., 2010), the interaction between field traffic organization and tillage systems and its effects on the quality of soil structure the whole field area is not well studied and therefore not easily accessible for practical optimisation.

Studying the combined effects of field traffic organisation and tillage system on agronomic and environmental aspects is the aim of a field experiment at Tänikon, Switzerland. On an arable soil and in a crop rotation, typical field mechanisation is used to apply two field traffic and three tillage treatments as experimental factors, resulting in well-defined field areas with characteristic wheeling and tillage history, and therefore presumably with a particular evolution of soil structure.

Today a typical field traffic organisation in Switzerland is defined by a) the use of field operations with different working widths and depths, b) a mostly random traffic pattern for tillage, fertilization and harvest operations, and c) temporary traffic lanes for spraying and fertilization operations. In most cases, the aim is to eliminate adverse effects of field traffic on soil structure before installing the next main crop by a deep tillage of the whole field area, thereby increasing porosity and reducing stability of the soil.

With respect to sustainable soil management, this way of soil structure evolution may be questionable: Randomly affecting the soil structure of a high proportion of the field area and afterwards routinely alleviating structural damages may not be the optimum solution regarding soil quality, ecological side-effects and management expenditures (Weyer 2007). Given the increasing availability of low-intensity tillage and seeding techniques as well as precise guidance systems, other solutions may be more promising.

In random traffic farming (RTF), machine widths are chosen as available and field traffic is only in certain crops and for certain operations organised, generally leading to the wheeling of practically the whole cultivated area in the course of time. In controlled traffic farming (CTF), machine widths of the different field operations are closely matched and all field passages are restricted to permanent traffic lanes (Chamen, 2006, Webb & Blackwell, 2004, Hamza & Anderson, 2005), leaving areas between the traffic lanes which are no longer wheeled (Fig. 1). As a consequence the soils of these no longer affected areas should develop an improved structure with e.g. better water infiltrability, permeability and storage capacity as well as rootability (Chamen et al, 2003).

Because of its specific mechanisation, CTF in a strict sense, as introduced e.g. on millions of hectares in wheat and sugar cane production fields of Australia, cannot simply be copied to every production region. In order to minimize the share of unproductive permanent traffic lanes, track and working widths of the agricultural machinery are widened. This results in elevated investments as well as in restricted versatility and usability of specific CTF machinery under typical central European production conditions, especially regarding field sizes and forms, topography, and road traffic system (Holpp et al, 2009).

In order a) to check the feasibility and the agronomic as well as the ecologic potential of CTF combined with reduced tillage and b) to compare CTF to other management systems under Swiss conditions, a field experiment was started in 2008 at Tänikon, Switzerland. In this paper the basic considerations regarding CTF solutions for Swiss conditions by the use of available standard machinery, the layout of the field experiment at Tänikon and first results on the effects of the investigated management systems on parameters of soil structure are presented.

Material and methods

Experimental design and treatments

In 2008 the CTF field trial was installed at the Swiss Federal Research Station in Tänikon on 539 m above sea level. The soil is a deep orthic luvisol with a loamy texture and an elevated content of stones (approx. 10 vol.% in the 0-90 cm depth range). Table 1 characterises the site with information on soil properties and on mean annual temperatures and total annual precipitations.

The intention was to test the feasibility of a CTF version adapted to Swiss site and management conditions, to combine it with no-tillage, and to compare this soil management treatment with other typical traffic x tillage-solutions. The comparison is done by monitoring the impacts of the different traffic patterns and the effects of the different tillage systems on soil structure, soil processes and agronomic parameters.

Table 1: Site characteristics of the CTF field trial at the Swiss Federal Research Station in Tänikon.

Soil characteristics	Topsoil 0-20 cm	Subsoil 30-50 cm
Clay [w/w]	19	20
Silt [w/w]	27	28
Sand [w/w]	52	51
org. C. [w/w]	1.16	0.94
pH (H_2O)	6.10	6.43

Weather characteristics	2009	2010	Long term mean[1)]
Precipitation [mm]	1138	1227	1042
Temperature [°C]	9.3	8.3	8.5

[1)] average for 1961-1990

On plots of 12 m width and of 30 m length, three combinations of tillage/seeding techniques and field traffic organisation were installed as soil management treatments: CTF no-till, RTF no-till and RTF plough (Table 2). The basic experimental layout corresponds to a randomized block design with three soil management treatments and four replications. In each soil management treatment, sub-areas are defined and monitored as follows: unwheeled, moderately wheeled and intensively wheeled in CTF, randomly wheeled in RTF (Table 2). Because there was a preceding experiment on effects of tillage/seeding techniques on soil properties and processes running at this field until 2007 (Anken et al., 2003), the layout of the soil management treatments in the CTF experiment starting in 2008 was adapted to the existing layout of tillage/seeding treatments, which offered the possibility to benefit from established tillage treatments: RTF plough followed the former plough treatment and RTF no-till followed the former no-till treatment; in contrast CTF no-till followed the shallow (10 cm) mulch seeding treatment. Therefore, at least in the first few years of establishing the CTF no-till system after the shallow mulch seeding, direct comparisons between the two no-till treatments (CTF no-till and RTF no-till respectively) have to be judged with care (Table 2).

Table 2: Treatments and sub-treatments of the CTF experiment. Unwheeled traffic zones occur in CTF no-till only. Whereas the traffic lanes Di and Pi are used for spraying of plant protection products and application of fertilizers, the permanent traffic lane Ci is used for all field operations. The moderately wheeled traffic zone in Cm is used for controlled field traffic during tillage and harvest operations. The area of the sub-treatments Dr and Pr is randomly wheeled during tillage, fertilizing and harvesting operations.

Treatment	Sub-treatment (traffic zone)		
	unwheeled	moderately (CTF) or randomly (RTF) wheeled	intensively wheeled
C (CTF no-till)	Cn	Cm	Ci
D (RTF no-till)		Dr	Di
P (RTF plough)		Pr	Pi

The adaptation of the CTF treatment to Swiss conditions consisted in two aspects. Firstly, a working width typical for Swiss farms was chosen (4.5 m). This lead to a traffic pattern resulting in three typical traffic zones: the unwheeled zone, the moderately wheeled zone and the intensively wheeled zone (Fig. 1).

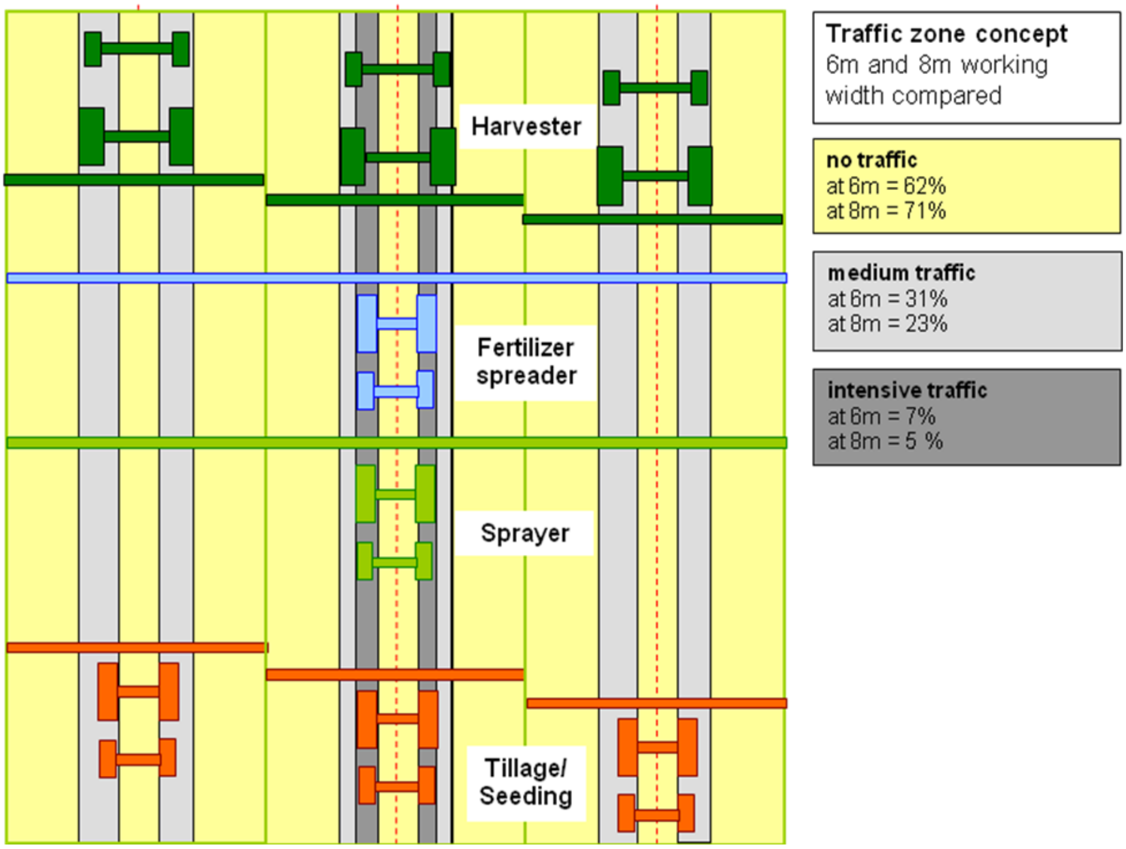

Figure 1: CTF adapted to available standard machinery leads to three traffic zones with differing mechanical impacts on soil structure: intensive traffic is concentrated on less than 10% of the cultivated area, whereas more than 60% of the cultivated area remains totally unwheeled. The moderately wheeled traffic zone is owed to the concessions to smaller working widths for tillage/seeding and harvesting operations and to low pressure tyre equipment respecting the requirements of physical soil protection.

Secondly all the traffic lanes must – according to the Swiss ordinance on impacts on soil – be part of the productive soil surface and are therefore subject to soil protection measures. Because of that the machines driving on the traffic lines have to meet the requirements of physical soil protection and will be equipped with the necessary (wide) tyres. This means also that the traffic lines in both the moderately and the intensively wheeled zone are cultivated in the same way as the unwheeled zone. Altogether, these two adaptations of the CTF treatment are leading to a higher proportion of wheeled zones, especially moderately wheeled zones, as compared with CTF solutions in e.g. Australia.
The three soil management treatments are running in the crop sequence winter wheat (2009), winter barley (2010), two years of ley (2011/12), and presumably silage maize (2013). Field operation dates as well as fertilization and plant protection were the same in all three treatments.

Mechanisation
Specific tillage/seeding machines: in the RTF plough treatment a two-furrow plough of 0.70 m working width and a 3 m rotary harrow seeding combination is used; in the RTF no-till a 2.25 m no-till seed drill, and in the CTF no-till treatment a 4.50 m no-till seed drill, respectively, is used.
Harvesting machines: in all treatments a combine harvester with a working width of 4.50 m and a tractor-driven mowing combination for forage harvest are used (Table 3).
The rest of the machines is the same for all three treatments - only the field traffic organisation differs. Spraying of plant protection products and application of fertilizers are carried out from a traffic lane in the middle of each experimental plot. In agreement with best

practice in physical soil protection, all self-propelled machines are equipped with appropriate tyres, which are operated with the minimum necessary tyre inflation pressure (Table 3).

Table 3: Machines, tyres and tyre inflation pressures used in the CTF experiment.

Machine	Empty weight [kg]	Front axle Tyre	Front axle Inflation pressure [kPa]	Rear axle Tyre	Rear axle Inflation pressure [kPa]
Same Dorado 75: plough, cultivator	3’950	360/70R20	80	420/70R30	80
John Deere 6920S: no-till	7’320	540/65R28	80	650/65R38	80
Fendt 411: plough/seed drill	5’770	420/70R24	80	460/85R34	80
John Deere 2254: combine harvester	12’900	800/65R32	100	540/65R24	120

Parameters and methods

Soil structure is characterized by bulk density, total porosity, macropore volume and air permeability. These structural parameters are determined from the same cylindrical soil samples of 100 mm diameter and 60 mm height; in the sub-treatments Ci, Cm, Cn, Dr and Pr (see Table 2) of blocks 2 and 3 soil samples are taken in 8 replications from 10 to 16 (topsoil) and from 35 to 41 cm depth (subsoil) every year in spring (with appropriate soil conditions during April and May) after structural equilibration during winter. Bulk density is determined by weighing and measuring the saturated height of the samples, total porosity by calculation using bulk density and analyzed particle density. Macropore volume is analysed by determining the height and weight of the soil samples after saturation and following desorption to 60 hPa; air permeability is determined by measuring the air flow passing the sample conditioned to 60 hPa vertically with an overpressure of 2 hPa.

The experimental harvest is done by hand in order to characterize plant productivity in the partially narrow traffic zone areas. Due to a hailstorm in May 2009, winter wheat was severely harmed, so no yield measurements were possible. Winter barley in 2010 and ley in 2011 (several cuts) could be harvested as intended.

Statistical analysis

Data were statistically analyzed using the software STATISTICA 9.1 of StatSoft Inc. In ANOVA sub-treatments were analyzed in a univariate design with fixed factors; means were compared using the grouping procedure of Tukey (1949). In nonparametric comparison of multiple samples sub-treatments were used as grouping factors.

Results and discussions

Results of topsoil measurements in winter wheat as the first crop of the CTF experiment in April 2009 clearly indicated that topsoil structure of Pr was of a totally different quality compared to the no-till treatments with CTF and RTF respectively: all soil structure parameters showed that the topsoil of the no-till treatments was much more compact than that of Pr (Fig. 2).

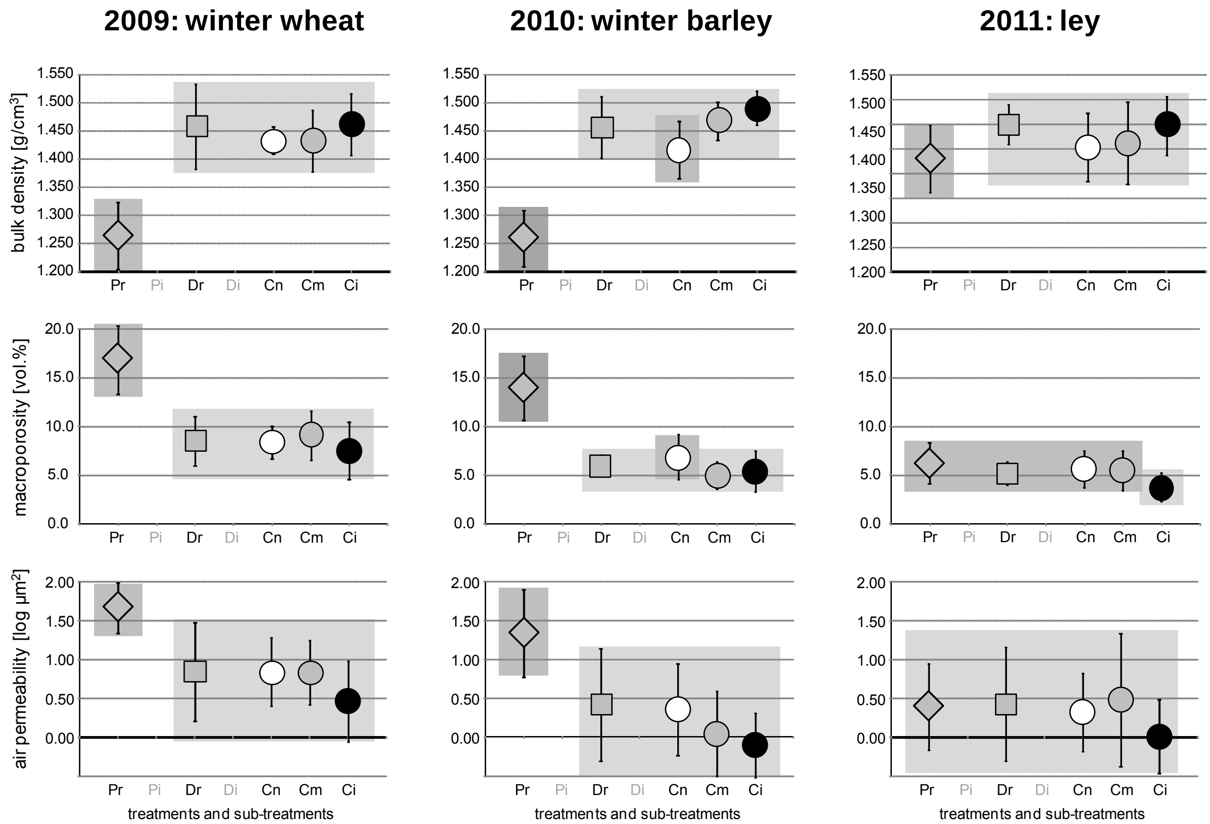

Figure 2: Topsoil structure, expressed as bulk density, macroporosity and log of air permeability (both at 60 hPa) in the first three years of the CTF experiment at Tänikon. In each case soil sampling was done in spring at a soil depth of 10-16 cm in two field blocks. Plotted are means and standard deviations; means in the same rectangle (same shade of grey) are statistically equivalent according to Tukey (1949).

At the same time, no statistically significant differences between the no-till treatments and any of its traffic zone sub-treatments could be detected; only a tendency of Ci to have the densest structure was identifiable in all topsoil parameters.
In the second experimental year 2010, with winter barley, soil in the Pr treatment was still considerably less compact than in the no-till treatments (Fig. 2). Again, no statistically significant differences were noticeable in the no-till treatments and the traffic zone sub-treatments; however a tendency of Cn to have slightly better values than the remaining no-till sub-treatments Cm, Dr and Ci could be detected.
In the third experimental year (2011), the values of soil structure parameters for Pr were no longer clearly higher than in the other treatments, so the differences to the other treatments were only small (Fig. 2). Comparing the traffic zone sub-treatments in CTF and RTF no-till treatments, the parameters characterizing soil structure did not differ in a statistically significant way; still, Ci had a tendency to a worse structural quality.
The effects of the experimental treatments on soil structure in spring are quite clear in the first three experimental years: ploughing the topsoil (before winter wheat and winter barley) resulted in a much looser soil than no-tillage, irrespective of the traffic scheme. However, as

soon as ploughing was skipped, as before ley in 2011, soil structure quality of the Pr treatment approximated that of the no-till treatments. The field traffic organisation in the CTF no-till treatment proved to be of minor importance during these first experimental years: whereas the sub-treatments Cm and Dr did not differ at all, slight indications of an improvement of soil structure in Cn could be found only in 2010. One reason for this could be that the CTF no-till treatment was installed on a soil which had been managed by shallow mulch seeding before; and so - in contrast to the Dr treatment, which had been established on a long-term no-till soil – the soil structure of the CTF no-till treatment was not yet adapted to the new management regime.

Winter barley yield was higher in the Pr and Cn sub-treatments than in Cm and Dr (Fig. 3). The reason for the low yield level was probably a drought period during early summer, resulting in a low thousand seed weight. The first two harvests of ley in 2011 showed lower yields in the Ci sub-treatment for both cuts. The highest yields were found in the ploughed and randomly trafficked treatment Pr. The remaining sub-treatments did not show statistically significant differences.

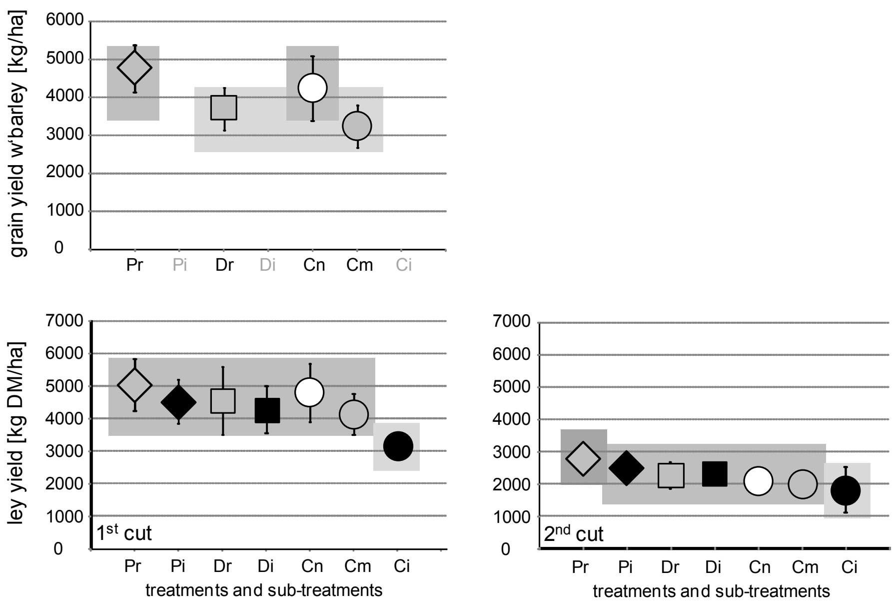

Figure 3: Yields of winter barley in 2010 (standardized at 15% humidity) and the first two cuts of ley in 2011 (dry matter). Plotted are means and standard deviations; means in the same rectangle (same shade of grey) are statistically equivalent according to Tukey (1949).

Conclusions

Theoretical considerations suggest that a stricter organisation of field traffic ("controlled traffic") could have advantages for the evolution of soil structure.

First results after three experimental years show clear differences between the topsoil structure of ploughed and no-till treatments, but only small and inconsistent differences in soil structure depending on the traffic impact.

As far as yield results may be related to soil structure, higher yields in the CTF experiment are generally associated with a better soil structure quality. In this respect the RTF plough treatment Pr shows consistently high yields. Astonishingly, a marginally better soil structure quality in the Cn compared to the remaining sub-treatments correlated also with a better yield.

After three experimental years the available results are not sufficiently significant, and the structural development of the treatments cannot yet be clearly identified. Therefore the applicability of a CTF concept at the arable experimental site cannot be assessed properly at the moment.

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